DICK

Plain base plates for columns

Architectural Engineering

B. S.

1907

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PLAIN BASE PLATES

FOR

COLUMNS

BY

CARL RANKIN DICK

THESIS

FOR

DEGREE OF BACHELOR OF SCIENCE

IN

ARCHITECTURAL ENGINEERING

COLLEGE OF ENGINEERING

UNIVERSITY OF ILLINOIS

PRESENTED JUNE, 1907

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UNIVERSITY OF ILLINOIS

June 1 1907

THIS IS TO CERTIFY THAT THE THESIS PREPARED UNDER MY SUPERVISION BY

Carl Rankin Dick

ENTITLED Plain Base Plates for Columns

IS APPROVED BY ME AS FULFILLING THIS PART OF THE REQUIREMENTS FOR THE

DEGREE OF Bachelor of Science in Architectural Engineering

N. Clifford Ricker
Instructor in Charge

APPROVED: N. Clifford Ricker

HEAD OF DEPARTMENT OF Architecture.

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INTRODUCTION

This subject, Base Plates, was suggested to the writer, as a possible thesis subject, by Dr. Ricker, his professor. After some investigation, both on the part of the writer and by Dr. Ricker, the subject was chosen.

Up to this time there had been no actual tests made on base plates. The exact action of the forces on the plates, and the stresses produced in them were not known. Plates were designed by "Rules of Thumb", which in many cases proved to be unsatisfactory and uneconomical. The object of this thesis is to derive theoretical formula by which base plates may be designed, and to test their accuracy by actual experiments performed on them.

Dr. Ricker had deduced such formulas, for simple base plates, before the writer commenced this thesis. It was the work of the writer to design plates according to these formulas and subject them to destructive tests, thus proving or disproving the truth of the assumptions made by Dr. Ricker. (The plates tested were designed to carry a load of 20000# and a safe unit pressure of 50# per sq. in.)

The subject is treated under the following heads; General Statement; Derivation of Formulas; Design of Plates Tested; and Discussion of Results.

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GENERAL STATEMENT

The purpose of a base plate is to distribute the weight of a column and its load over a sufficient area, so that the pressure per sq. unit of this area, and the maximum fibre stress will not exceed the maximum values permitted by ordinance, or by safe practice.

This maximum pressure per sq. in. allowed by the Chicago Ordinances is as follows:

On concrete masonry	173.61#
On dressed dimension stone	173.61#
On rough dimension stone	138.89#
On brickwork in Portland Cement	173.61#
On brickwork in ordinary cement	125.00#
On brickwork in lime mortar	90.28#

The center of the plate should always coincide with the resultant of all loads on its upper face. A steel plate is necessarily of uniform thickness, being cut from a rolled plate. For economy a cast iron plate is reduced in thickness from the central square or circle, on which rests the column, to a minimum at the outer edge. This is usually not less than 3/8", but depends upon the dimensions and thickness of the plate.

For the sake of simplicity in formulas, those for cast iron plates are based on the assumption of sharp outer edges of the plate. When the outer edges are 3/8" thick or more, the tendency to increase the tensile fibre stress is more than neutralized by the increase in the moment of inertia of the fracture section of the plate, so that its actual strength will be slightly greater than that given by the formulas, which are therefore entirely safe.

The Chicago Ordinance prescribes the following maximum fibre stresses in pounds per sq. in, at the

greatest distance from the neutral axis of the fracture section.

Steel, tension or compression	16000#
Cast iron, tension	2500#
Cast iron, compression	10 000#

DERIVATION OF FORMULA
FOR
SIMPLE BASE PLATES
NOTATION USED

The base plates are assumed to break on approximately a straight line, which is termed the fracture line.

Let A = total area of base plate in square inches.

Let p_1 = total pressure of plate on masonry in pounds.

Let p = maximum permissible pressure in pounds per square inch.

Then $A = \frac{p_1}{p}$ = req. area of plate. (1)

Let M = bending moment in inch pounds acting at right angles to fracture line.

Let a = area in square inches of the portion of the plate outside the fracture line.

Let l = lever arm in inches of this pressure area "a".

Then $M = apl$ = bending moment (2)

And $f\frac{I}{c}$ = resisting moment in inch pounds of fracture section.

f = maximum permissible fiber stress.

I = moment of inertia of fracture section.

c = distance in inches from neutral axis of fracture section to its most distant fiber.

t = thickness of plate in inches.

Then $M = apl = f\frac{I}{c}$ (3)

No. 2

DERIVATION OF FORMULA

STEEL SQUARE BASE PLATE

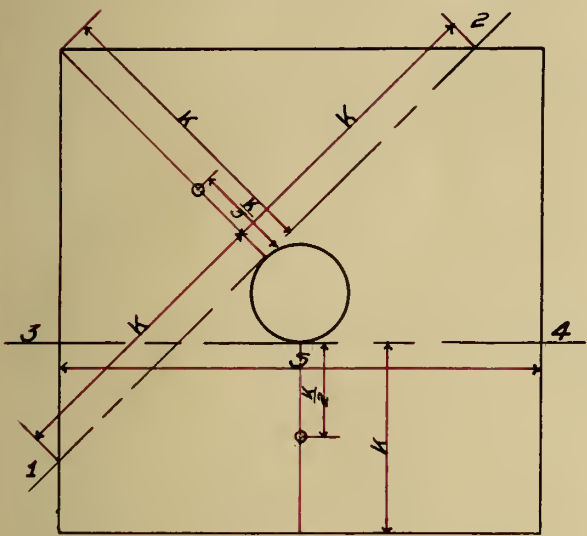


FIG. 1.

FRACTURE LINE 1-2 FIG. 1

The plate is assumed to fracture along lines 1-2 or 3-4.

Here $a = K^2$

$l = \frac{K}{3}$

$M = apl = \frac{pK^3}{3}$ = external bending moment.

$f\frac{I}{C}$ = resisting moment.

$$f\frac{I}{C} = \frac{pK^3}{3}$$

$$f\frac{I}{C} = \frac{16000 \times 2Kt^3}{12} \times \frac{2}{t} = \frac{16000Kt^2}{3}$$

Equating and reducing

$$M = \frac{pK^3}{3} = \frac{16000Kt^2}{3}$$

$$t = \frac{K}{40}\sqrt{\frac{p}{10}} = \text{thick. req.} \qquad (4)$$

FRACTURE LINE 3-4

Here $a = Ks$, $l = \frac{K}{2}$; $apl = \frac{K^2sp}{2}$ = exter. mom.

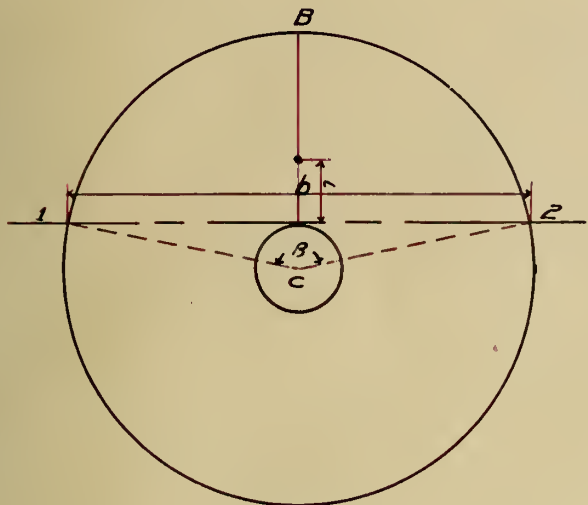
$$f\frac{I}{C} = \frac{16000st^3}{12} \times \frac{2}{t} = \frac{16000st^2}{6} = \text{resist. mom.}$$

Hence $M = \frac{pK^2s}{2} = \frac{16000st^2}{6}$

$$t = \frac{K}{40}\sqrt{\frac{3p}{10}} = \text{thick. req.} \qquad (5)$$

Apply formulas 4 and 5 and take laggest value of "t".

STEEL ROUND BASE PLATE



FIG·2·

FRACTURE LINE 1-2 FIG 2·

Join points 1 & 2 with center C, Measure angle $\beta = \angle 1C2$, at center subtended by segment 1B2· This angle may be easily calculated·

Then $A \times \frac{\beta}{360^\circ}$ = area of sector 1B2C (6)

$\frac{br}{2}$ = area of triangle 1C2 (7)

$A \times \frac{\beta}{360^\circ} - \frac{br}{2}$ = area of segment 1B2, outside of fracture line 1-2 (8)

And $\frac{b^3}{12a}$ = distance of C·G· from center of gravity of segment area· (9)

Finally $\frac{b^3}{12a} - r = l$ (10)

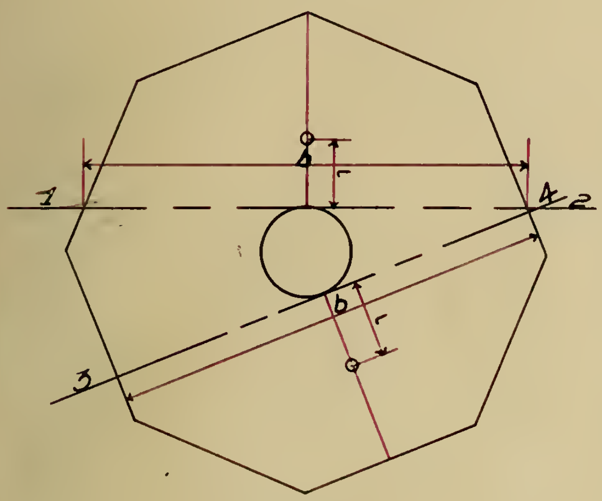
$$M = apl =$$

$$f\frac{I}{c} = \frac{16000bt^3}{12} \times \frac{2}{t} = \frac{16000bt^2}{6}$$

$$apl = \frac{16000bt^2}{6}$$

$$t = \frac{1}{40}\sqrt{\frac{3apl}{5b}} = \text{thick· req·}$$

STEEL OCTAGONAL BASE PLATE



FIG·3·

FRACTURE LINE 1-2

The area may be easily computed by dividing it into trapezoids and triangles.

The center of gravity may be located either graphically or anal

Then $M = apl$

$$= \frac{16000\,b\,t^2}{6}$$

$$t = \frac{1}{40}\sqrt{\frac{3apl}{5b}} = \text{thick. req. (12)}$$

Apply formula for each fracture line and take largest value of "t" for req. thickness.

CAST IRON SQUARE BASE PLATE

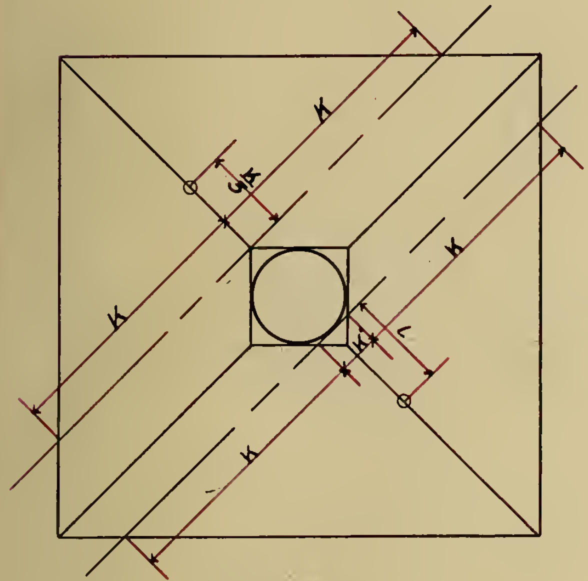


FIG. 4.

In the design of cast iron plates the edges are assumed to be sharp, hence the area of the fracture section is treated as though it were triangular in shape. Therefore the fiber stress (compression) most distant from the neutral axis may be taken $= 5000^{\#/\square''}$

FRACTURE LINE 1-2 FIG. 4.

$$M = apl = \frac{pK^3}{3}$$

$$f\frac{I}{c} = \frac{5000 \times 2Kt^3}{36} \times \frac{3}{2t} = \frac{2500\,Kt^2}{6}$$

$$t = \frac{K}{50}\sqrt{2p} = \text{thick. req.} \qquad (13)$$

FRACTURE LINE 3-4 FIG. 4.

The fracture section here contains a rectangular portion with length K', for which $f = 2500^{\#/\square''}$. The remainder consists of two triangular portions as before. Assuming that the total resisting moment of the three portions is as great when united as when separated.

$$\text{Then } M = apl = p\frac{\left(K+\frac{K'}{2}\right)^2}{3} = \frac{2500\,t^2}{6}(K+K')$$

$$t = \frac{1}{50}\sqrt{\frac{2p\left(K+\frac{K'}{2}\right)^3}{K+K'}} = \text{thick. req.} \qquad (14)$$

FRACTURE LINE 5-6 FIG. 5.

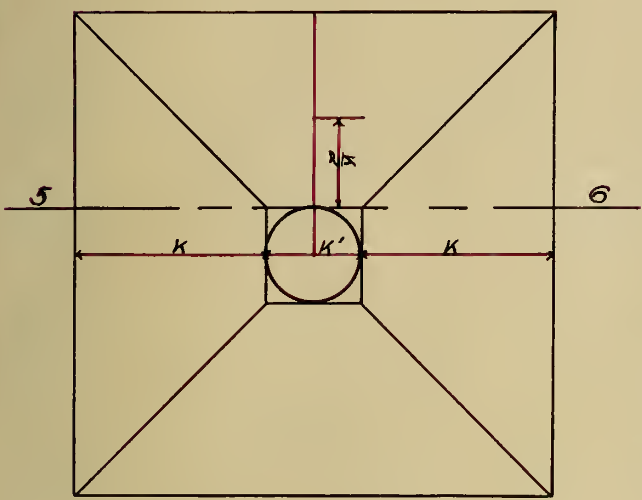
The rectangular middle portion here has a length of K'. The remainder consists of two triangular sections. Proceeding as in the last case:

$$M = apl = p\frac{K^2}{2}(2K+K')$$

$$f\frac{I}{c} = \frac{2500\,t^2}{6}(K+K')$$

$$t = \frac{K}{50}\sqrt{\frac{3p(2K+K')}{K+K'}}$$

As before use largest value for "t".



FIG·5·

The work may be easily checked by drawing the fracture section at a large scale, and by graphical methods locating the center of gravity and neutral axis; the determine its moment of inertia.

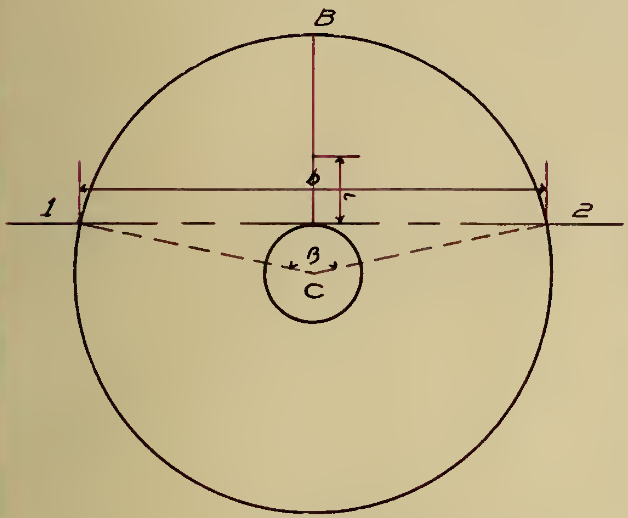
Let v = distance from neutral axis to bottom (tension).

Let $t-v$ = distance from neutral axis to top (compression).

Then make $f = 2500\frac{t-v}{v}$; write out value of $f\frac{I}{C}$ and compute t, which should practically as computed by formulas.

This method may be employed to determine actual resistance of ordinary base plates with edges $\frac{3}{8}''$ thick or more.

CAST IRON ROUND BASE PLATE



FIG·6·

FRACTURE LINE 1-2·FIG·6·

Area of segment outside fracture line is computed, center of gravity located, and leverarm "l" is determined as for Steel Round Base Plates.

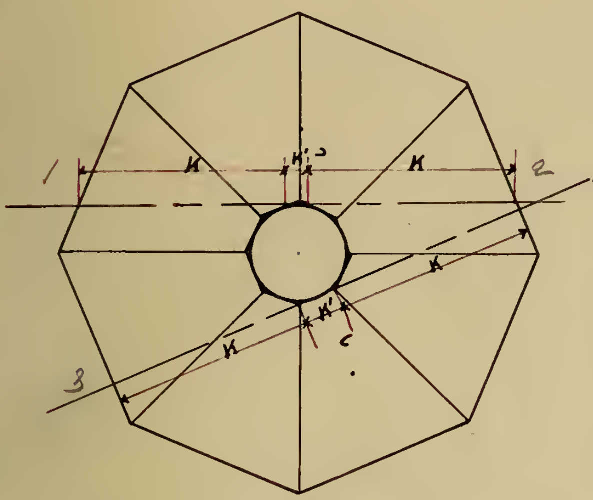
The edges of the plate are assumed to be sharp, so that the fracture section may be considered a parabola, which differs little from the actual hyperbola.

$$\begin{aligned} M &= apl \\ &= \frac{3750 \times 8bt^3}{175} \times \frac{5}{3t} \\ &= \frac{2000bt^2}{7} \end{aligned}$$

$$t = \sqrt{\frac{7apl}{2000b}} = \text{thick. req.} \qquad (16)$$

No 6.

CAST IRON OCTAGONAL BASE PLATE



FIG·7·

FRACTURE LINE 1-2 FIG·7·

Here the fracture section is made up of two triangular, two trapezoidal and one rectangular portion. to make the formula simplier and easier to work with, consider the fracture section made up of two triangular and one rectangular sections. The error will be on the safe side.

Then $apl = f\frac{I}{c} = \frac{2500}{6}t^2(K+K')$

$$t = \sqrt{\frac{6apl}{2500(K+K')}}$$

Apply formula for both fracture lines.

DESIGN
OF
BASE PLATES TESTED

The area and pressure per sq. in. of the plates tested was determined to a great extend by the capacity of the testing machine, at hand. Each plate was so designed as to have an area of 400 sq. in. The pressure per sq. in. "p" was taken at 50 pounds. Total pressure $p_1 = 20000^{\#}$

In the design, the load was assumed to be carried to the plate by a 4"-metal, C.I., hollow hub.

The plates were designed in accordance with the Chicago Building Laws, which permit a tensile fiber stress for cast iron, of $2500^{\#/\square''}$; for steel, of $16000^{\#/\square''}$.

Doctor Ricker's Formulas, derived under "Derivation of Formulas", were used to determine the required thickness.

STEEL SQUARE BASE PLATE FIG.1.

$A = 400^{\square''}$; $p = 50^{\#/\square''}$; Hub 4" in diam.

Fracture line 1-2

$$t = \frac{K}{40}\sqrt{\frac{p}{10}} = \frac{12.14}{40}\sqrt{\frac{50}{10}} = 0.6768''$$

Fracture line 3-4

$$t = \frac{K}{40}\sqrt{\frac{3p}{10}} = \frac{8}{40}\sqrt{\frac{150}{10}} = 0.775''$$

Make plate $\frac{13}{16}''$ thick.

STEEL ROUND BASE PLATE FIG. 2.

$A = 400^{\square''}$; $p = 50^{\#/\square''}$; Hub 4" in diam.

Fracture line 1-2.

$$400 = 3.1415\, r^2 \qquad r = 11.28''$$

$$\frac{b}{2} = \sqrt{11.28^2 - 2^2} = 11.06'' \qquad b = 22.12''$$

$$\frac{\angle 1C2}{2} = \tan^{-1}\frac{11.06}{2} = 79^\circ 45' \quad \angle 1C2 = 159^\circ 30'$$

$$\frac{400 \times 159.50}{360} = 177.22^{\square''} \text{ area } 1C2B$$

$$11.28 \times 2 = 22.56^{\square''} \text{ area } 1C2$$

$$a = 177.22^{\square''} - 22.56^{\square''} = 154.66^{\square''}$$

$$l = \frac{b^3}{12a} - r = \frac{22.12^3}{12 \times 154.66} - 2 = 3.84''$$

$$t = \frac{1}{40}\sqrt{\frac{3apl}{5b}} = \frac{1}{40}\sqrt{\frac{3 \times 154.66 \times 50 \times 3.84}{5 \times 22.12}} = 0.71''$$

Make plate $\frac{3}{4}$" thick.

STEEL OCTAGONAL BASE PLATE FIG. 3.

$A = 400^{\square''}$; $p = 50^{\#/\square''}$; Hub 4" in diam.

Fracture line 1-2, parallel to diam.

Area of Oct. $= 4r^2 \sin 45^\circ$ $\quad r$ = radius of circ. circle

$$r^2 = 100\sqrt{2} = 141.4^{\square''} \qquad r = 11.9''$$

$$b = 23.8'' - 2(0.82\bar{5}) = 22.15''$$

$$a = 144.5^{\square''} \qquad l = 4.32''$$

$$t = \frac{1}{40}\sqrt{\frac{3apl}{5b}} = \frac{1}{40}\sqrt{\frac{3 \times 50 \times 144.5 \times 4.32}{5 \times 22.15}} = 0.73''$$

Fracture line 3-4, parallel to side.

$$\frac{b}{2} = 11'' \qquad b = 22''$$

$$a = 156.4^{\square''} \qquad l = 3.85''$$

$$t = \frac{1}{40}\sqrt{\frac{3apl}{5b}} = \frac{1}{40}\sqrt{\frac{3 \times 50 \times 156.4 \times 3.85}{5 \times 22}} = 0.715''$$

Make plate $\frac{3}{4}$" thick.

CAST IRON SQUARE BASE PLATE FIG 4 & 5.

$A = 400^{\square''}$; $p = 50^{\#/\square''}$; Hub 4" in diam.

Fracture line 1-2

$$K = \frac{28.3}{2}'' - 2.83'' = 11.32''$$

$$t = \frac{K}{50}\sqrt{2p} = \frac{11.32}{50}\sqrt{100} = 2.264''$$

Fracture line 3-4

$$K = 12.14'' - 0.83'' = 11.31''$$

$$K' = 2 \times 0.83'' = 1.66''$$

$$t = \frac{1}{50}\sqrt{\frac{2p\left(K+\frac{K'}{2}\right)^3}{K+K'}} = \frac{1}{50}\sqrt{\frac{100(11.3+.83)^3}{11.31+1.66}} = 2.35''$$

Fracture line 5-6

$$K = 8''$$

$$K' = 4''$$

$$t = \frac{K}{50}\sqrt{\frac{3p(2K+K')}{K+K'}} = \frac{8}{50}\sqrt{\frac{150 \times 20}{12}} = 2.53''$$

Make plate $2\frac{9}{16}''$ thick at center.

CAST IRON ROUND BASE PLATE FIG. 6.

$A = 400^{\square''}$; $d = 22.56''$; $p = 50^{\#/\square''}$; Hub 4" in diam.

See computations for steel plate

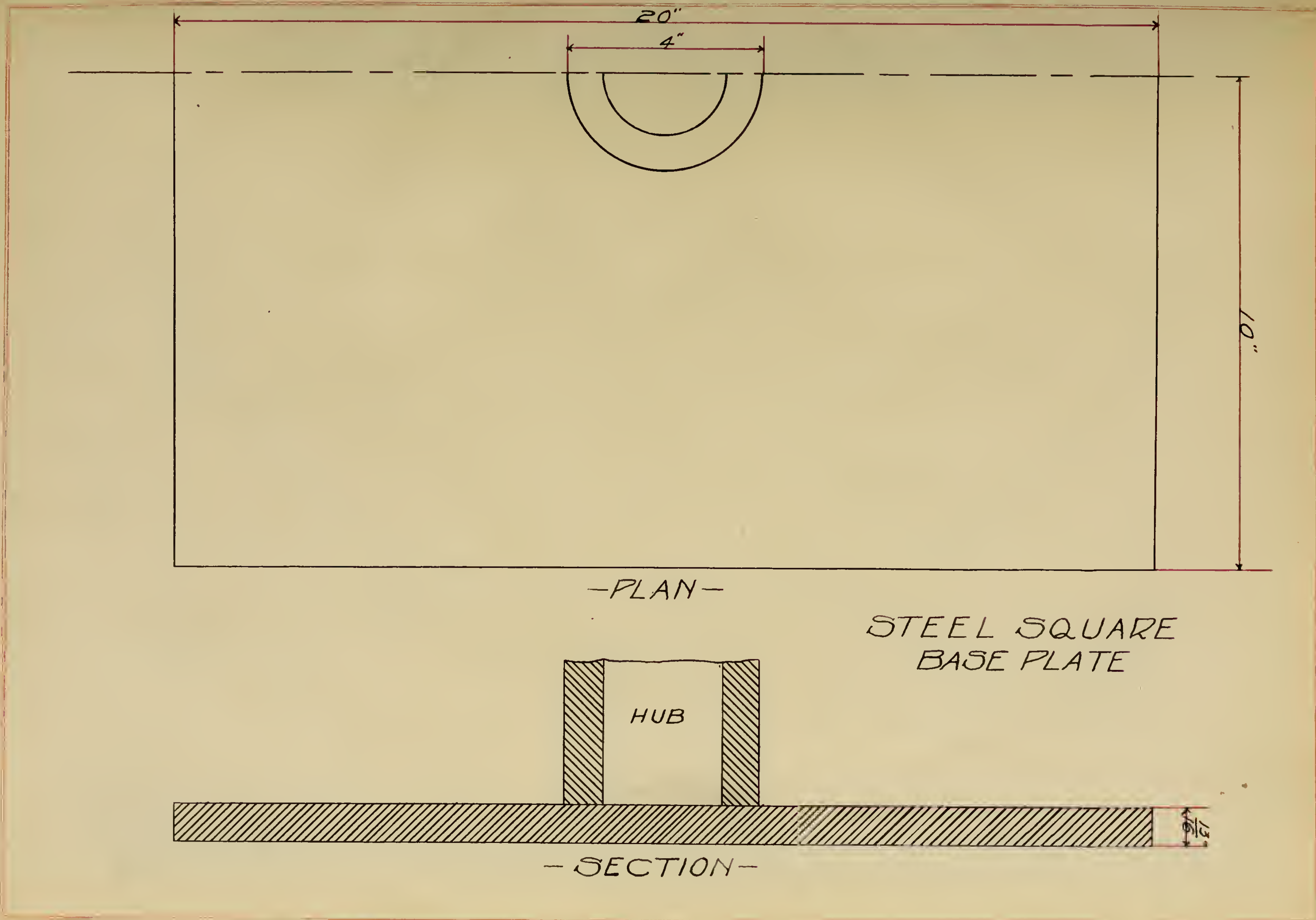
$$a = 154.66^{\square''}$$

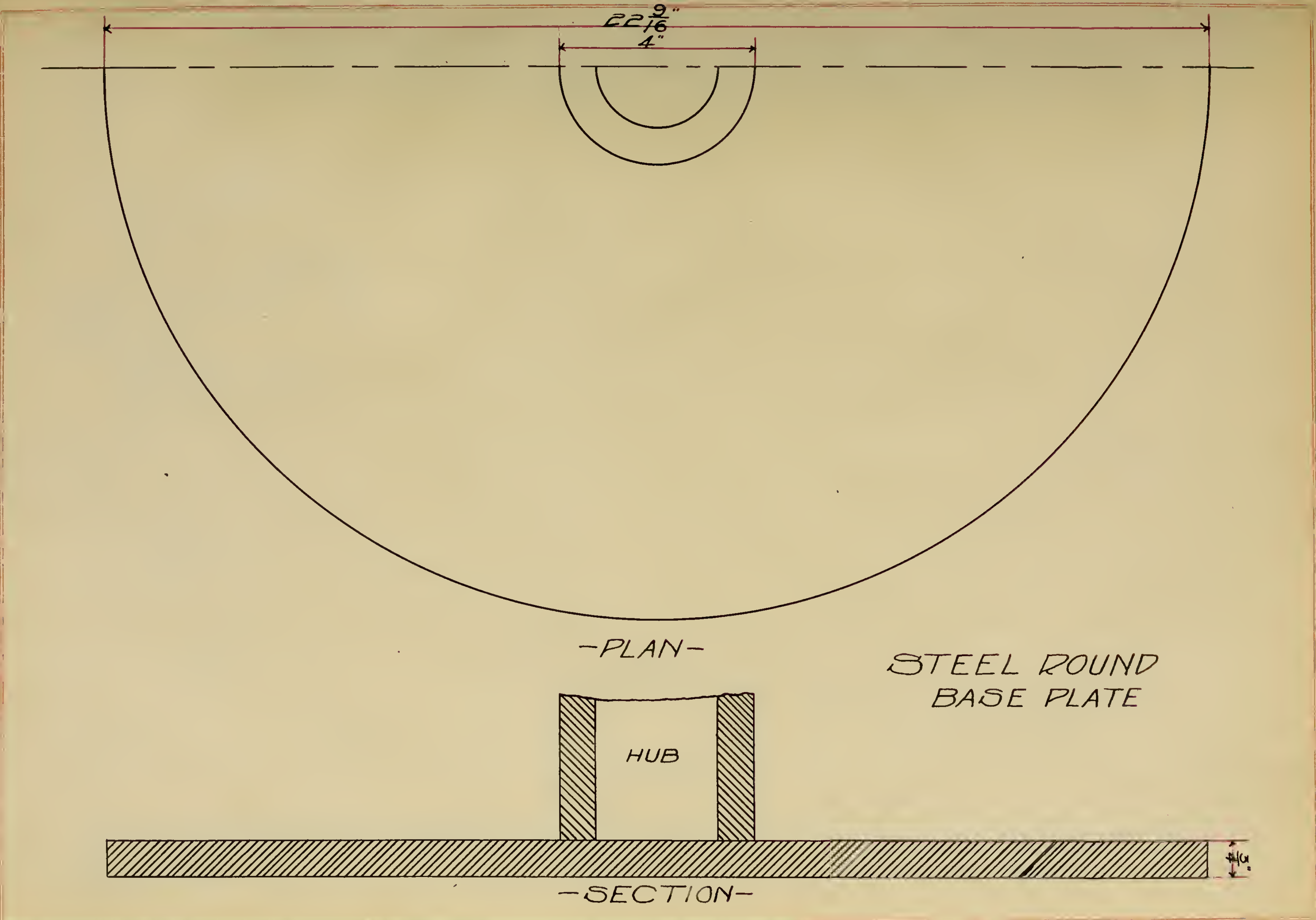
$$l = 3.84''$$

$$b = 22.12''$$

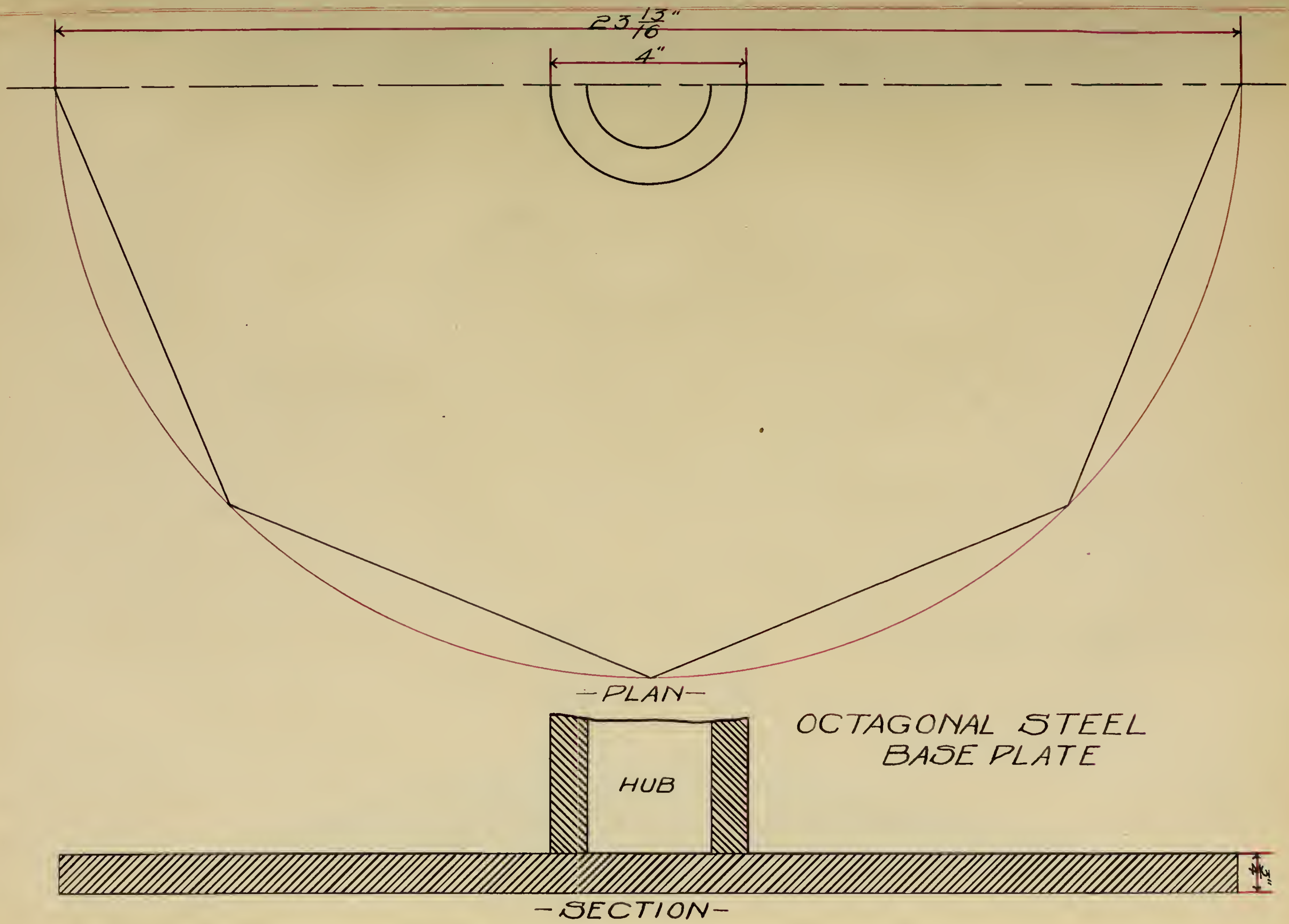
$$t = \sqrt{\frac{7apl}{2000b}} = \sqrt{\frac{7 \times 154.66 \times 50 \times 3.84}{2000 \times 22.12}} = 2.167''$$

Make plate $2\frac{3}{16}''$ thick at center.

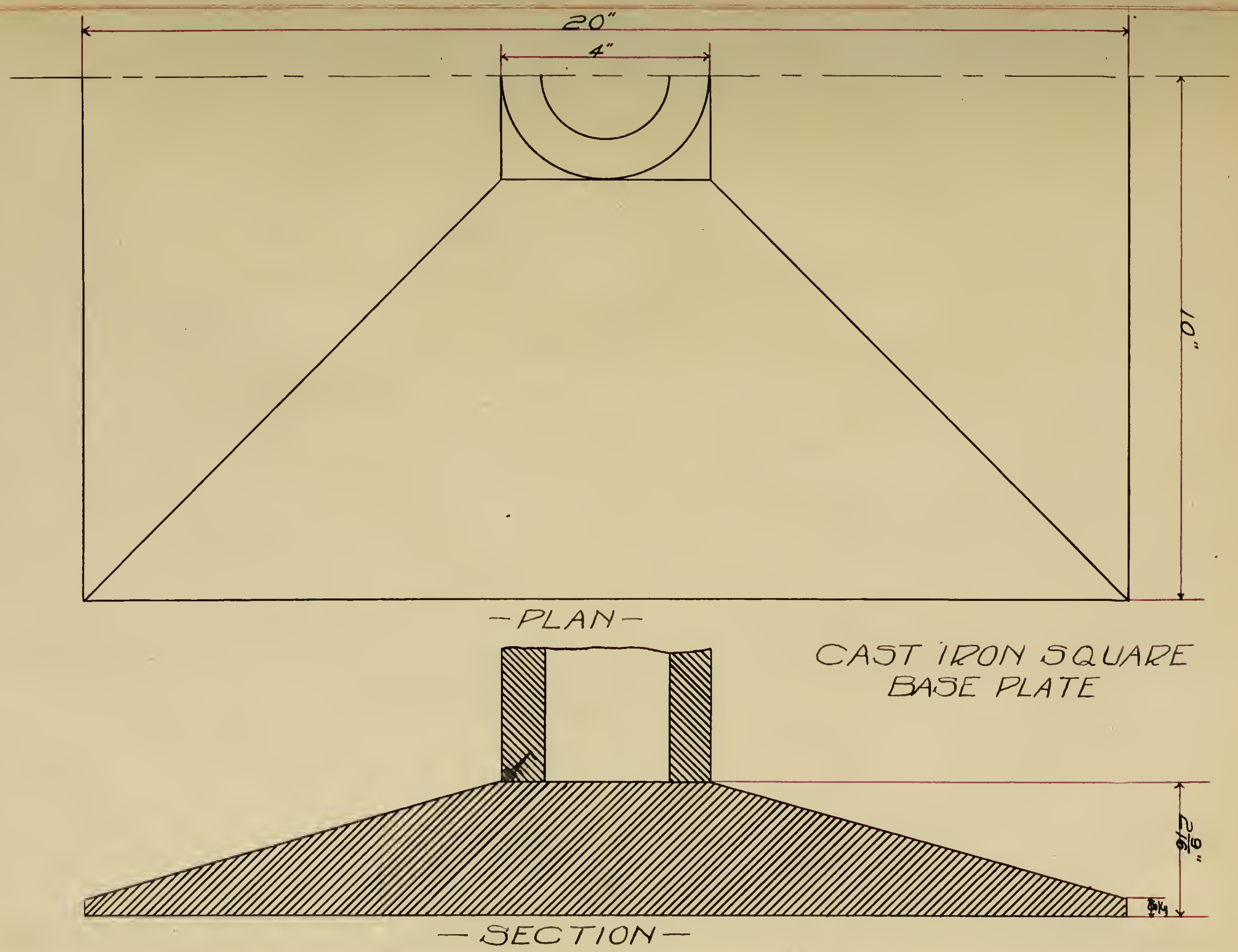

20"
4"
10"
-PLAN-
STEEL SQUARE
BASE PLATE
HUB
13/16
- SECTION -



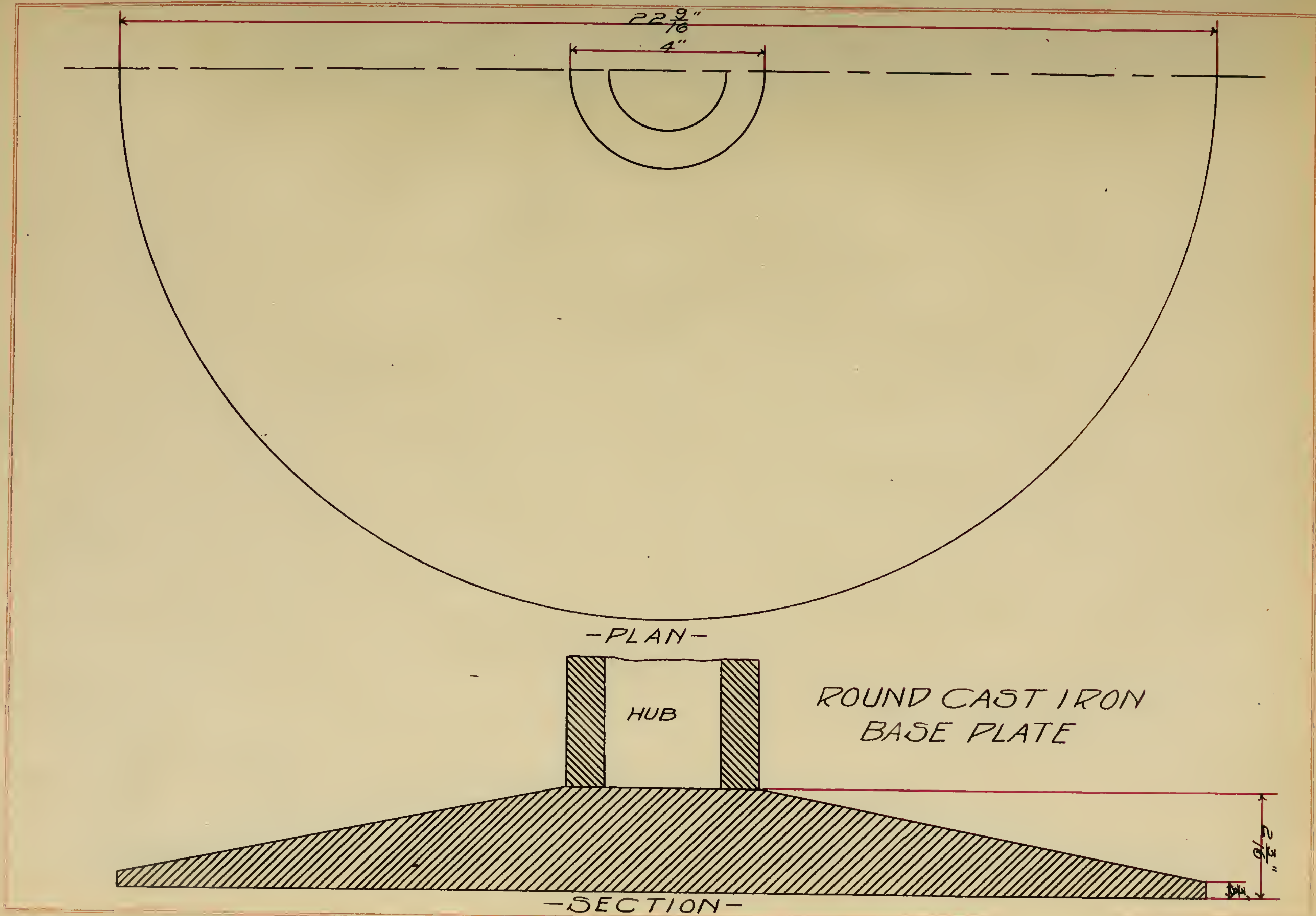
22 9/16"
4"
-PLAN-
STEEL ROUND
BASE PLATE
HUB
3/4"
-SECTION-



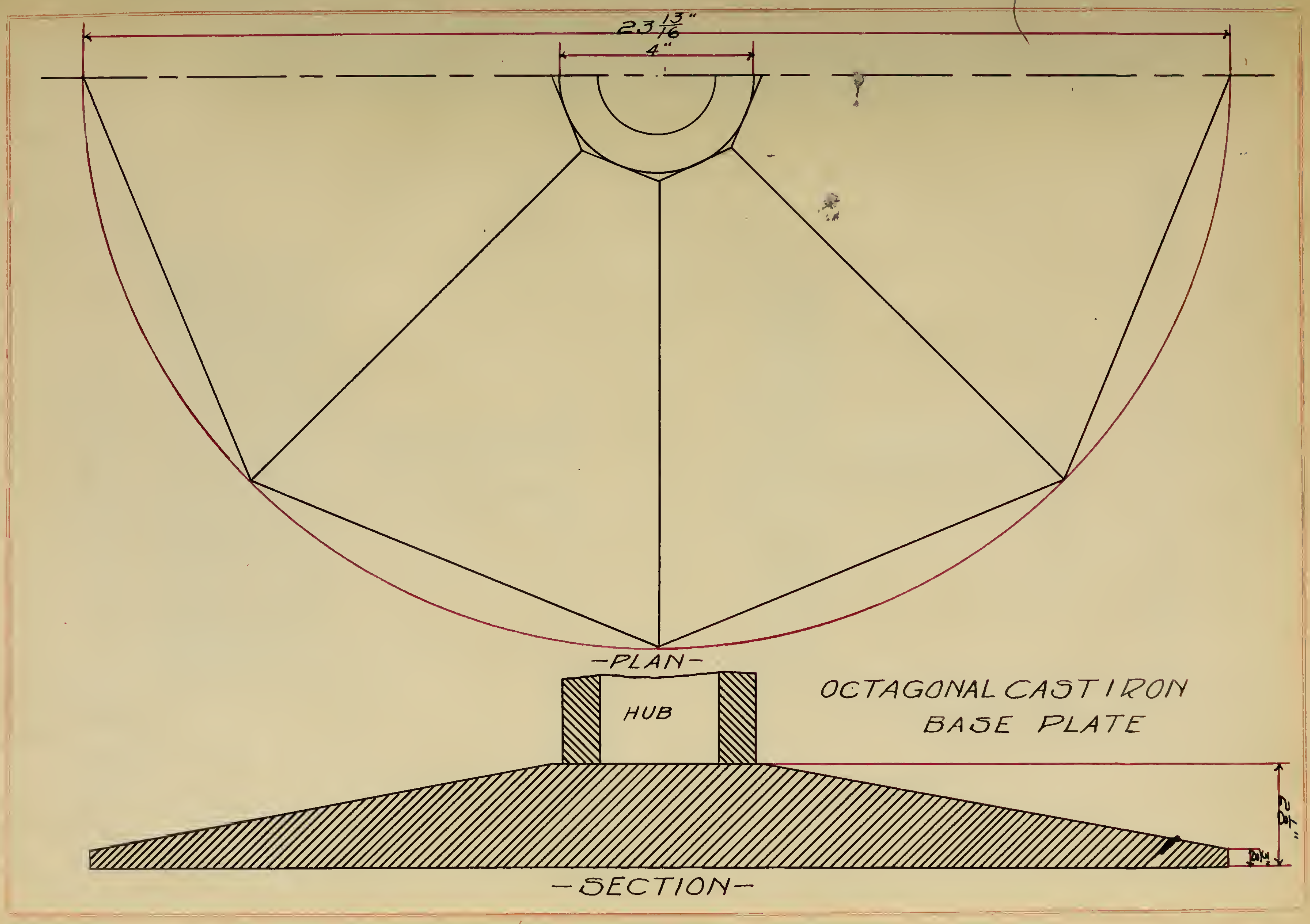
OCTAGONAL STEEL
BASE PLATE



20"
4"
10"
- PLAN -
CAST IRON SQUARE
BASE PLATE
2 9/16"
3/4
- SECTION -

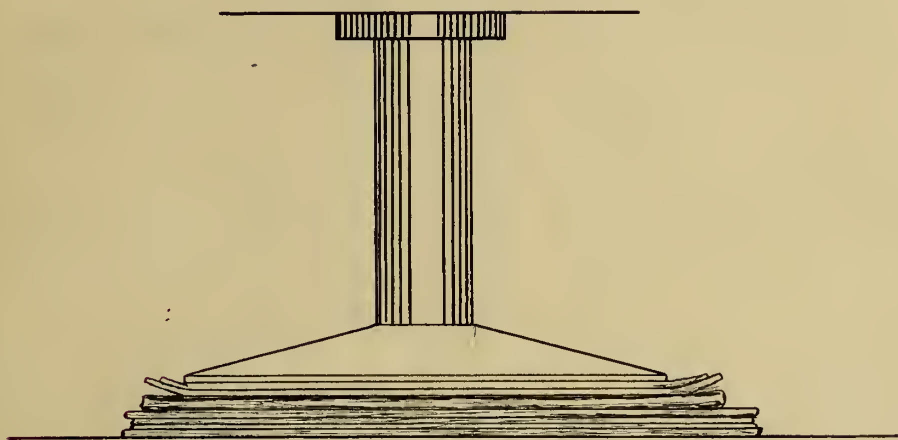


22 9/16"
4"
-PLAN-
HUB
ROUND CAST IRON
BASE PLATE
2 3/16"
-SECTION-

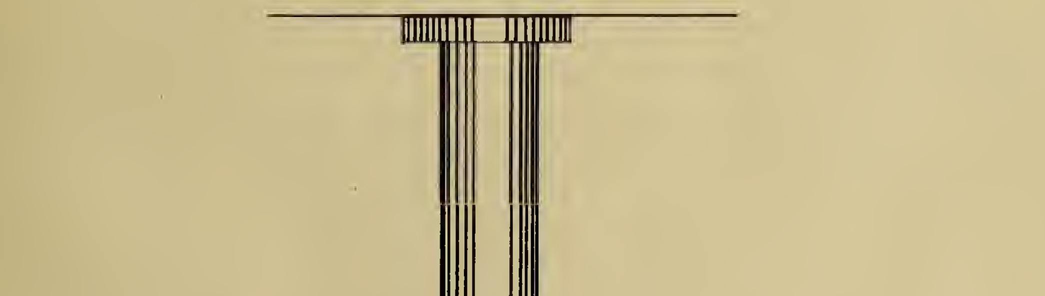


$23\frac{13}{16}$"
4"
-PLAN-
HUB
OCTAGONAL CAST IRON
BASE PLATE
$2\frac{1}{8}$"
-SECTION-

CUSHIONS USED



PLATES A1#, B1#, C 1#, WERE TESTED ON THIS CUSHION.



PLATES A2#, A3#, B2#, B3#, C2#, C3#, WERE TESTED ON THIS CUSHION

RESULTS OF TESTS

The tests were made in the 600000# testing machine. Two cushions were used in the tests. In selecting cushions, the aim was to get one, which would reproduce practical conditions as closely as possible.

The first cushion consisted of a folded comforter, two folded blankets, and two layer of $\frac{1}{8}$" packing rubber. This was placed on the machine in the order mentioned; the comforter being placed on the bed of the machine, the plate resting on the rubber. A cast iron hub, 12" long, $\frac{3}{4}$" metal, was used to apply the load, A drawing of this cushion is shown on the preceeding page. Plates; A1, B1, C1, were tested on this cushion. In these cases the load was applied slowly and evenly, until the plate failed. The breaking load was recorded and the method of failure noted in each case.

The second cushion used (see drawing on preceeding page) was made up of eleven layers of $\frac{7}{8}$"x4", oak boards; the boards being placed in layer, running in alternate directions, as shown in drawing. The plate to be tested was laid directly on the top layer of this cushion. Plates; A2, A3, B2, B3, C2, C3, were tested on this cushion. The load was applied with increments of 50000#. After each increment of load was added, the deflection of the plate was measured. The deflections were measured from the head of the machine. Measurements taken in this way, showed deflections for the plates varying from $\frac{1}{8}$" to $\frac{3}{16}$". The plates were tested to destruction; the breaking load was recorded and the method of failure noted for each plate.

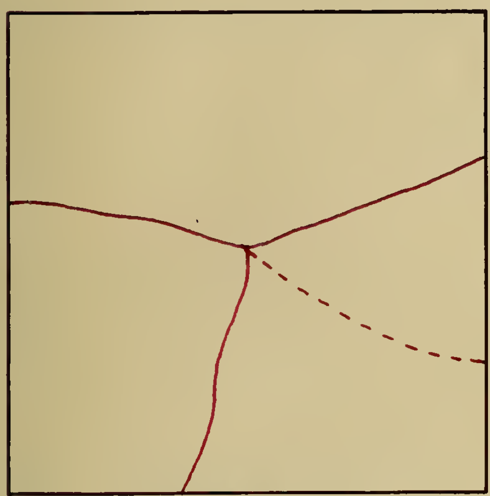
The steel plates were also tested on the wood cushion. The load in each case was applied in increments of 20000#, and the deflections were taken and

recorded for each increment of load applied. A load of 120000# was applied to each plate, in increments as before stated, and then removed. The plates were then found to have taken a permanent set. The center, where the hub rested, was pressed down, the plate assuming a dished shape. The results are given in the tables.

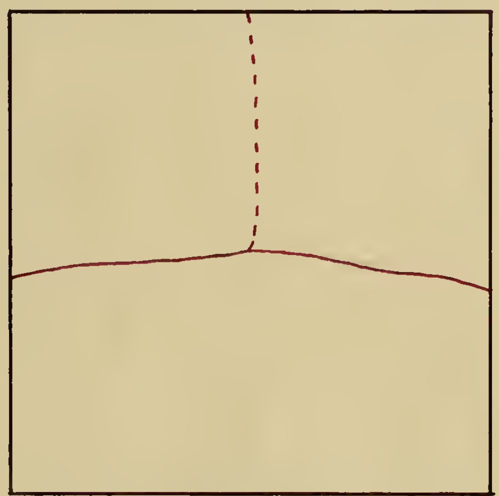
No 8

CAST IRON SQUARE BASE PLATES TESTED

RED LINES SHOW LINES OF FAILURE
BREAKING LOAD GIVEN BELOW EACH



A1#
155000#



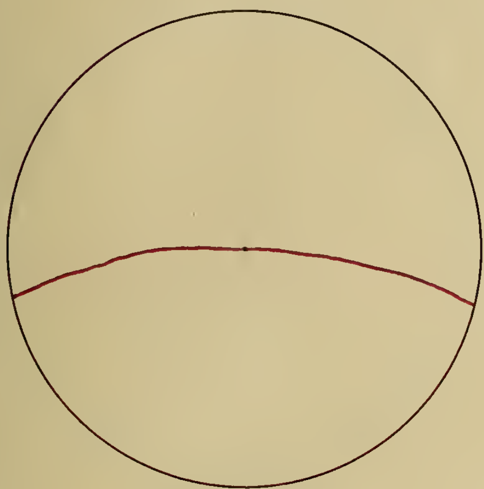
A2#
268000#

A3#
213500#

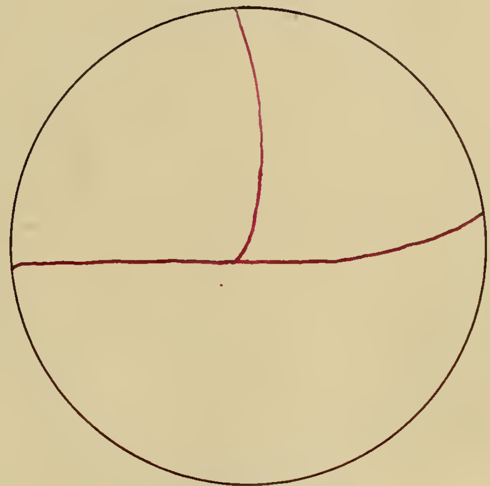
No 10

CAST IRON ROUND BASE PLATES TESTED

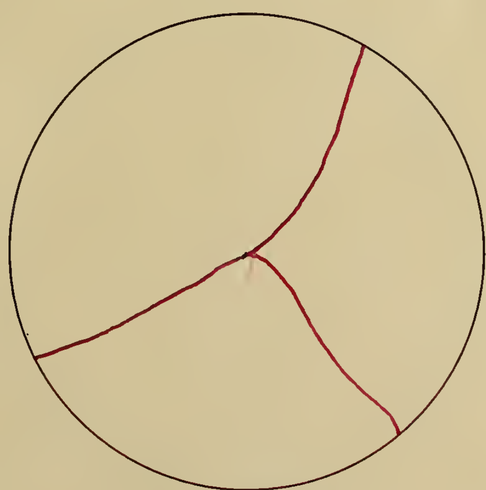
REDLINES SHOW LINES OF FAILURE
BREAKING LOAD GIVEN BELOW EACH



B 1#
139000#



B 2#
276000#

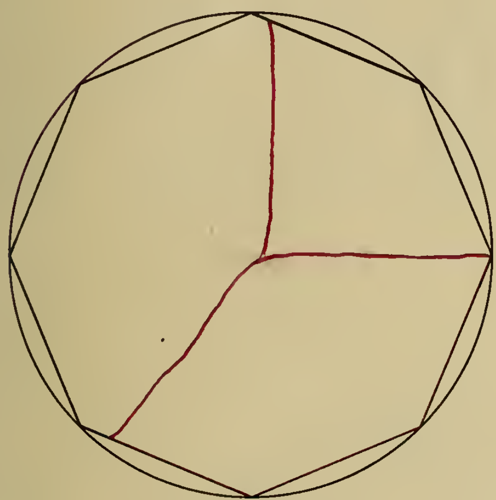


B 3#
275500#

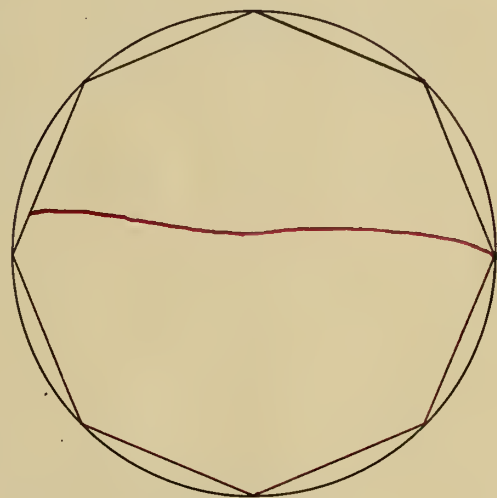
No 9

CAST IRON OCTAGONAL BASE PLATES TESTED.

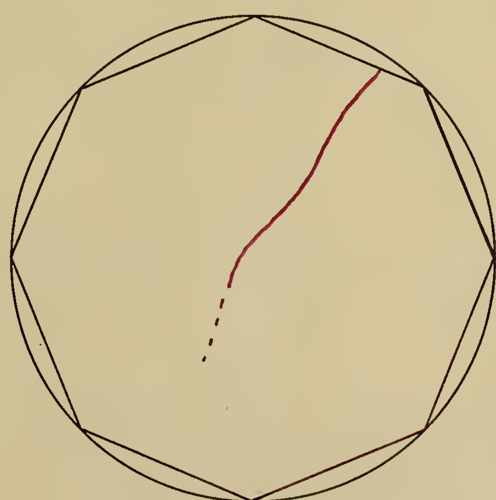
REDLINES SHOW LINES OF FAILURE
BREAKING LOAD GIVEN BELOW EACH



C 1#
67000#



C 2#
121000#



C 3#
117300#

DATA
FOR
STEEL PLATES TESTED
SQUARE

LOAD	DEFLECTION READ							
	1	2	3	4	5	6	7	8
00	7.22	7.22	7.24	7.21	5.51	5.51	5.51	5.51
22000#	7.12	7.16	7.21	7.21	5.51	5.51	5.51	5.50
45600#	7.04	7.08	7.05	7.05	5.50	5.51	5.51	5.50
61000#	7.02	7.05	7.02	7.02	5.46	5.51	5.51	5.47
81300#	6.98	6.99	6.95	6.95	5.48	5.51	5.54	5.48
100500#	6.92	6.93	6.88	6.90				
121000#	6.82	6.88	6.80	6.85				
500#	6.98	7.05	6.98	6.95	5.49	5.51	5.46	5.50

ROUND

LOAD	DEFLECTION READ							
	1	2	3	4	5	6	7	8
500#	7.23	7.23	7.23	7.23	5.52	5.51	5.52	5.52
21000#	7.22	7.22	7.21	7.21	5.50	5.50	5.49	5.49
40500#	7.15	7.17	7.15	7.15	5.50	5.51	5.50	5.50
60000#	7.10	7.11	7.08	7.09	5.50	5.49	5.50	5.49
100500#	7.01	7.03	7.00	7.01				
120000#	6.96	6.98	6.94	6.95				
500#	7.08	7.09	7.06	7.07	5.50	5.49	5.49	5.49

OCTAGONAL

LOAD	DEFLECTION READ							
	1	2	3	4	5	6	7	8
500#	7.25	7.26	7.26	7.26	5.50	5.50	5.53	5.53
21000#	7.18	7.19	7.19	7.19	5.49	5.48	5.54	5.54
58000#	7.13	7.14	7.12	7.12	5.47	5.48	5.48	5.48

DISCUSSION OF RESULTS
CAST IRON PLATES

All the cast iron plates tested, broke on lines running through the center of the plate; each breaking into two or three pieces, as shown in the sketches of the plates after fracture occurred. This is not in accordance with the assumptions made in the derivation of the formulas for the plates, where the fracture line was taken tangent to the hub. To design plates considering the fracture line to pass through the center of them, would require finding the center of pressure of the applied load, and the center of pressure of the forces acting on the underside of the plate. From these, could be computed, the moment at the fracture line through the center. Equating this to the resisting moment of the plate at this point and solving, the required thickness at the center may be determined. This would require much more labor and time to design a plate, as the formulas would become much more complex. That this increased amount of work would not be repaid is shown by the tests.

The deflection of the cast iron plates was not noticeable until the designed load had been multiplied several times. This shows that the plates distributed the load over the bearing area uniformly.

The plates broke far in excess of the designed load; the factor of safety ranging from seven to thirteen. This shows that a greater fibre stress than that permitted by the Chicago Ordinance could be used with safety. A fibre stress of 3000#/□", for cast iron in tension is authorized by the ordinances of several large cities in the United States

In Conclusion

1. The formulas for the design of cast iron plates

may be used with safety.

2. A greater fibre stress than that permitted by the Chicago Ordinance could be used with safety.

3. Cast iron is better adapted for base plates than steel, as it gives a uniform distribution of the load over the bearing area for a greater range of loading.

4. Cast iron will not deteriorate as rapidly as steel when in a damp place, and for this reason cast iron should be preferred.

STEEL PLATES

It was impossible to test the steel plates until fracture occurred, as the steel would only bend and take a permanent set, after the elastic limit of the material had been passed.

The steel plates failed in accordance with the assumptions made in the derivation of the formulas for steel plates; the center at the hub was pushed down below the plane of the edges of the plate, leaving the plate dished in shape, after the elastic limit of the material had been exceeded and the load removed. As shown by the deflection readings for the tests on steel plates, there was no noticeable deflection when the load was applied, which the plate was designed to safely carry. This shows that the formulas deduced for steel plates are satisfactory; the plates distribute the load uniformly over the whole area covered by them. As the load was increased, the plates began to deflect, slowly at first, and more rapidly after the elastic limit of the material had been exceeded, as may be seen from the deflection readings.

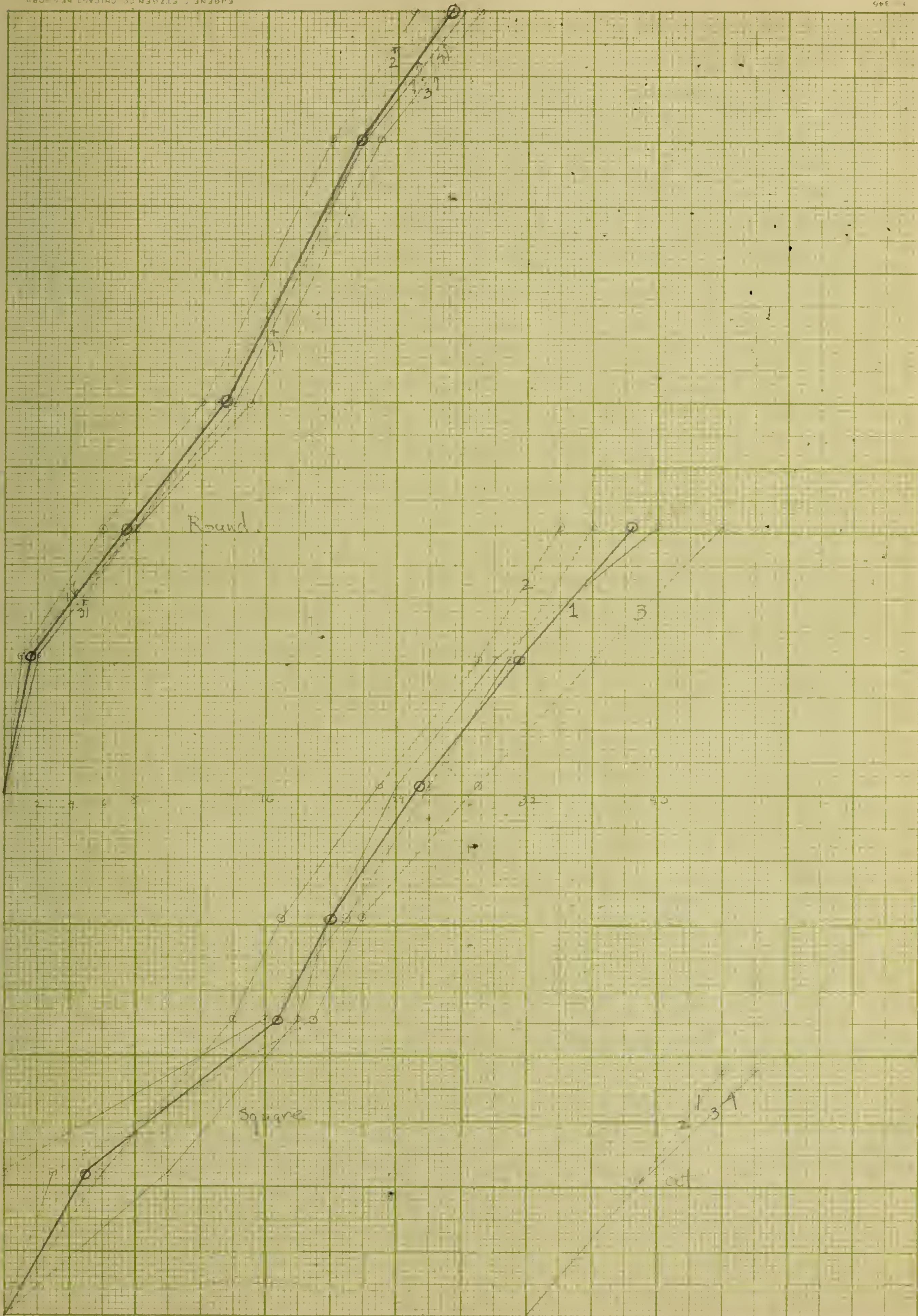
In Conclusion:

1. The formulas for the design of steel base plates are entirely safe.

2. The limit of 16000# fibre stress permitted by the Chicago Ordinance is perhaps too large, since marked deflections take place rapidly after this fibre stress has been exceeded.

3. Steel plates projecting more than two diameters of the hub, beyond it, should be designed for deflection, or it would be better to use a cast iron plate for large loads.

4. The circular is the most economical shape for a bearing plate.


Round
Square

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